Supersonic Particle Deposition (Cold Spray)

Phillip F. Leyman

US Army Research Laboratory
Weapons & Materials Research Directorate

Presented at HCAT Program Review Meeting
July 20-21 2004

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
JUL 2004		**00-00-2004 to 00-00-2004**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Supersonic Particle Deposition (Cold Spray)	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U. S. Army Research Laboratory,Weapons & Materials Research Directorate,Aberdeen Proving Ground,MD,21005**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
24th Replacement of Hard Chrome Plating Program Review Meeting, July 20-21, 2004, Park City, UT. Sponsored by SERDP/ESTCP.

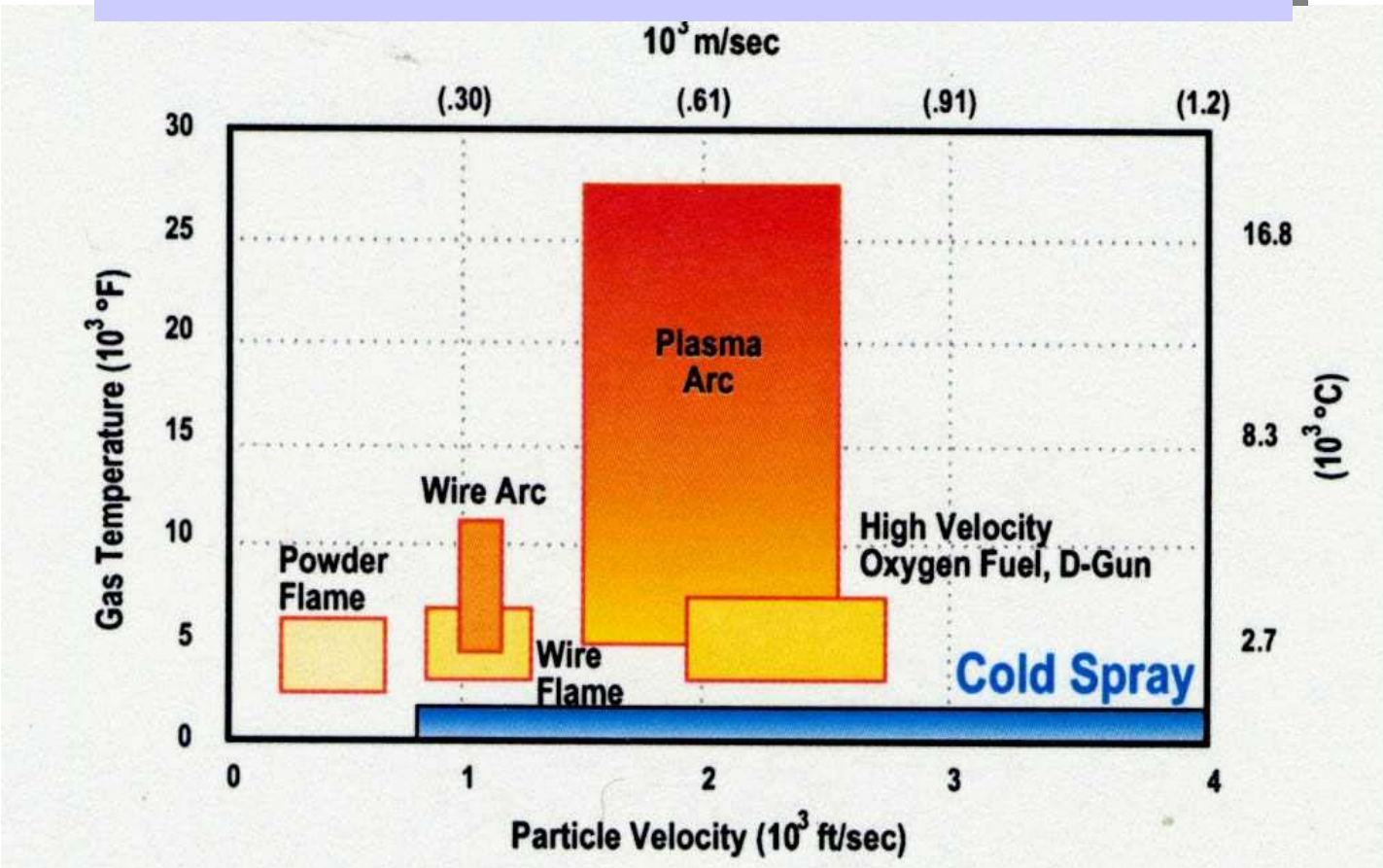
14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**24**	

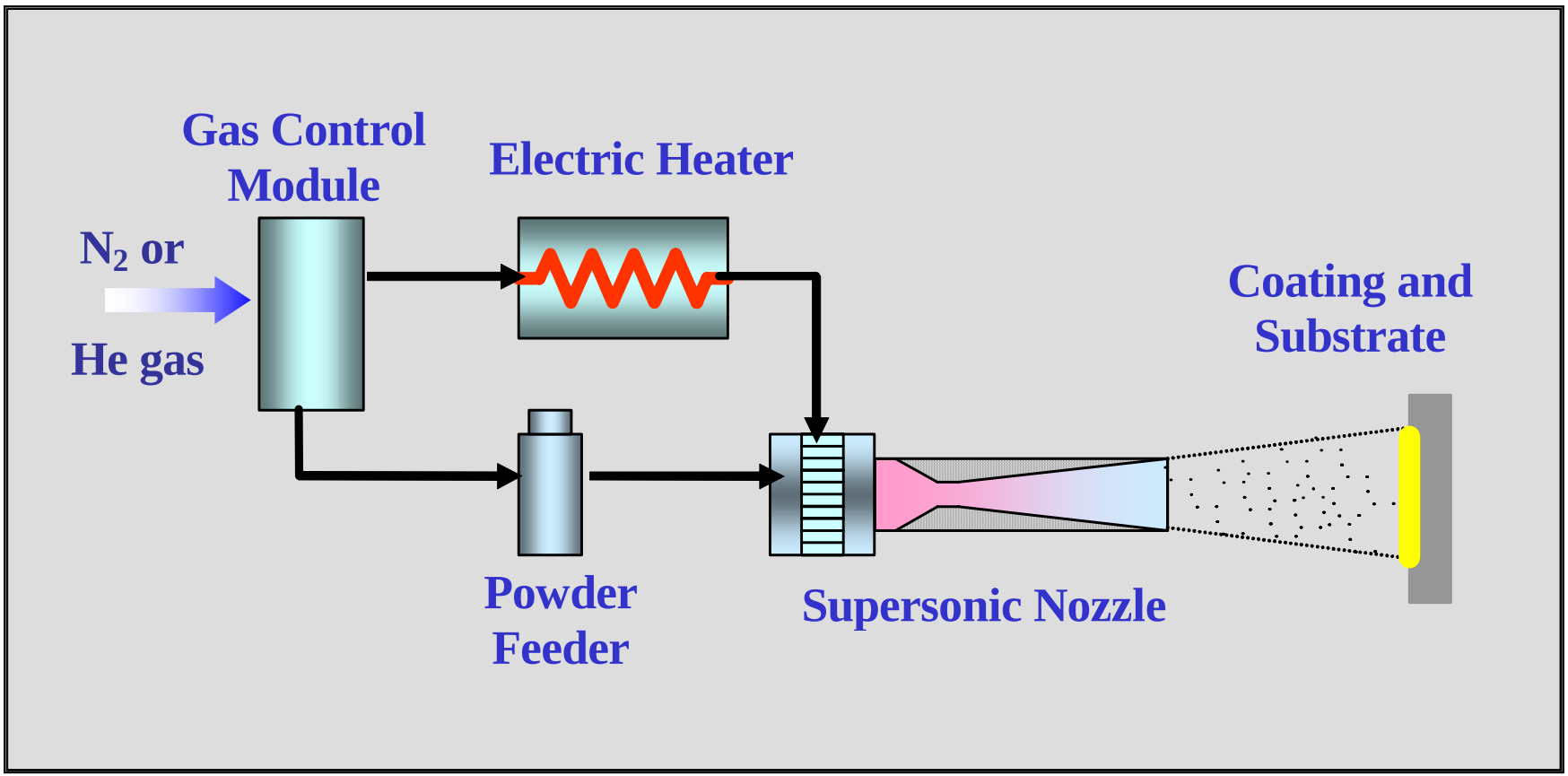
Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

SPD vs. Thermal Spray

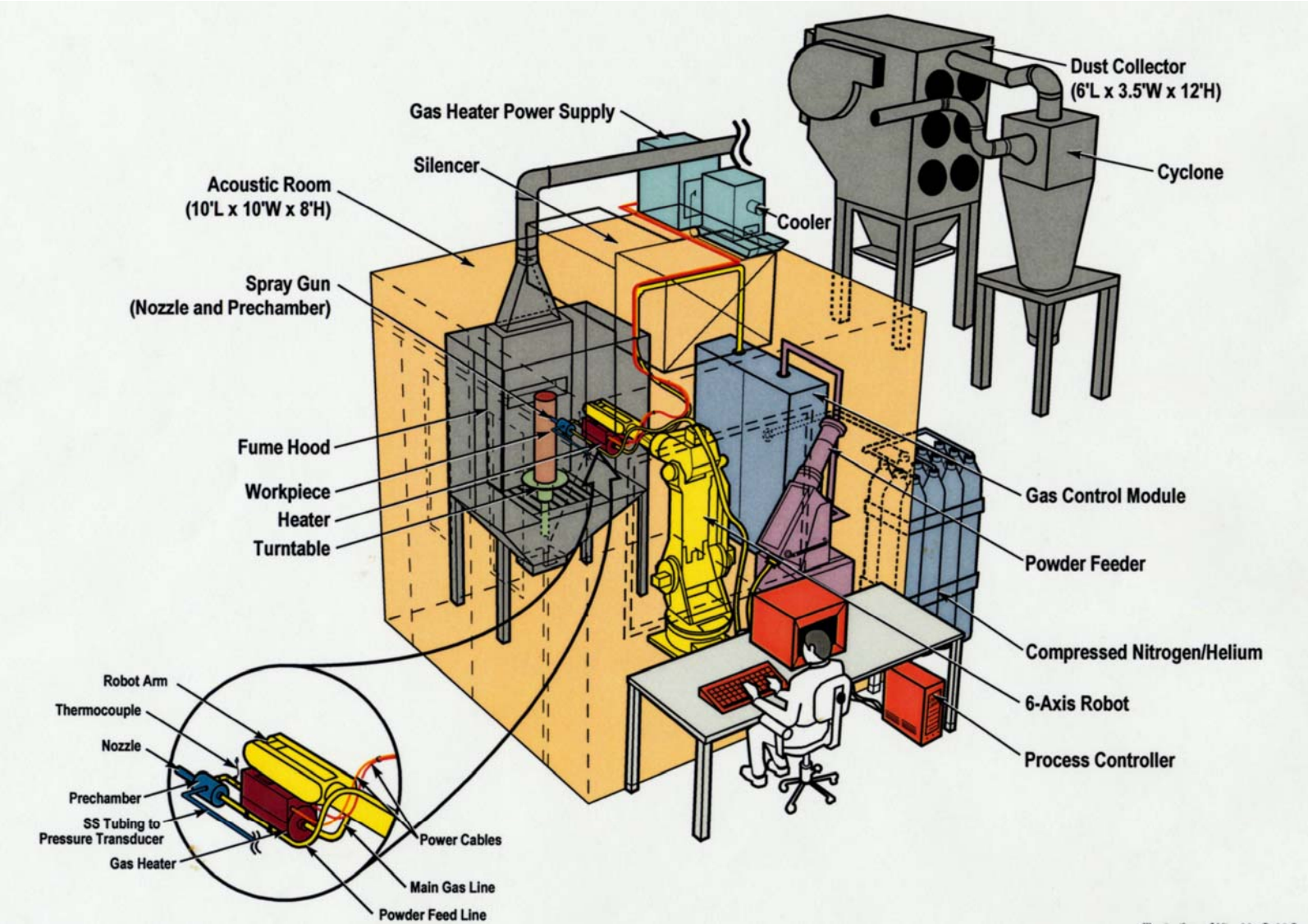


SPD uses lower temperatures, but higher particle velocities

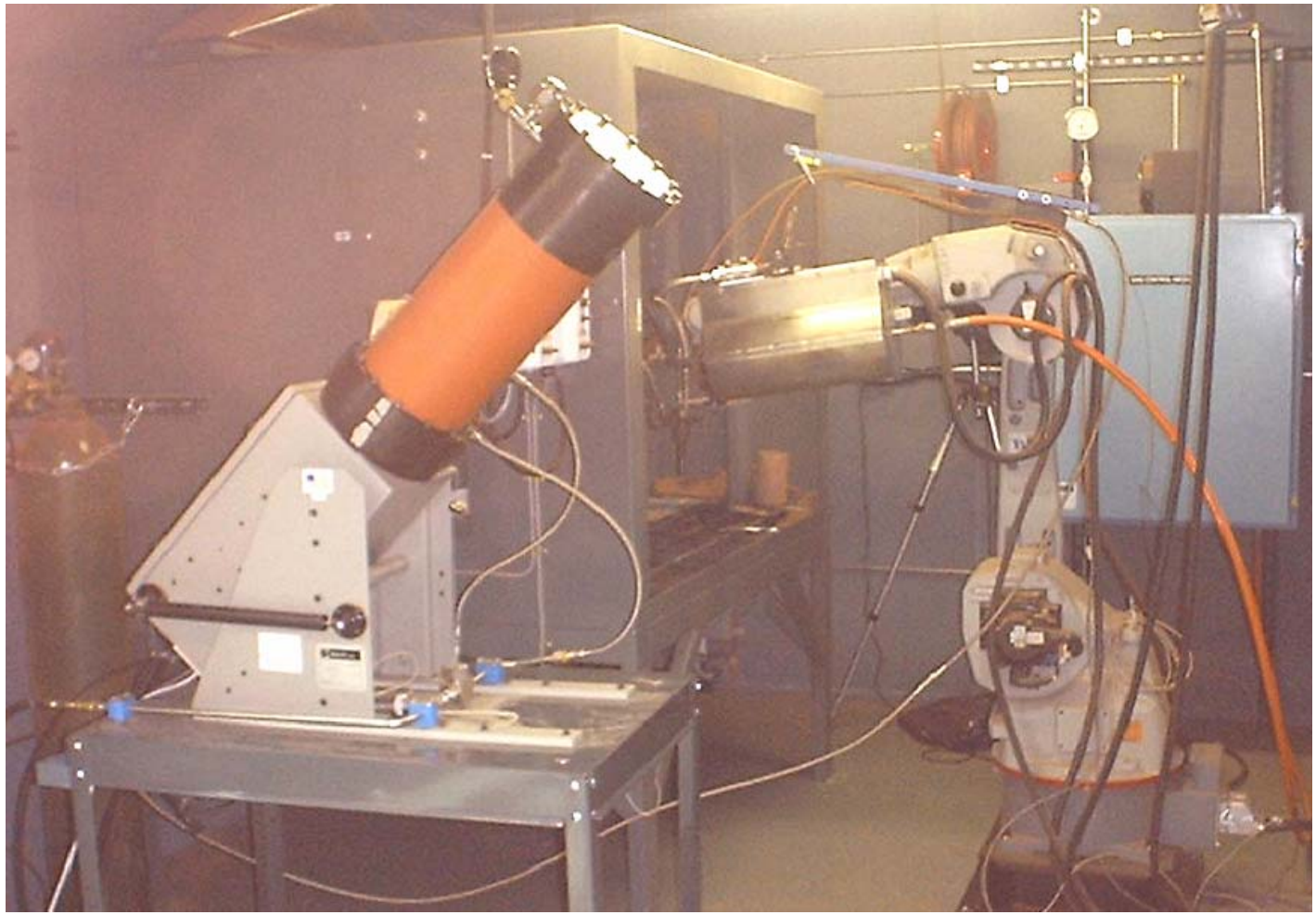
Supersonic Particle Deposition



System Arrangement



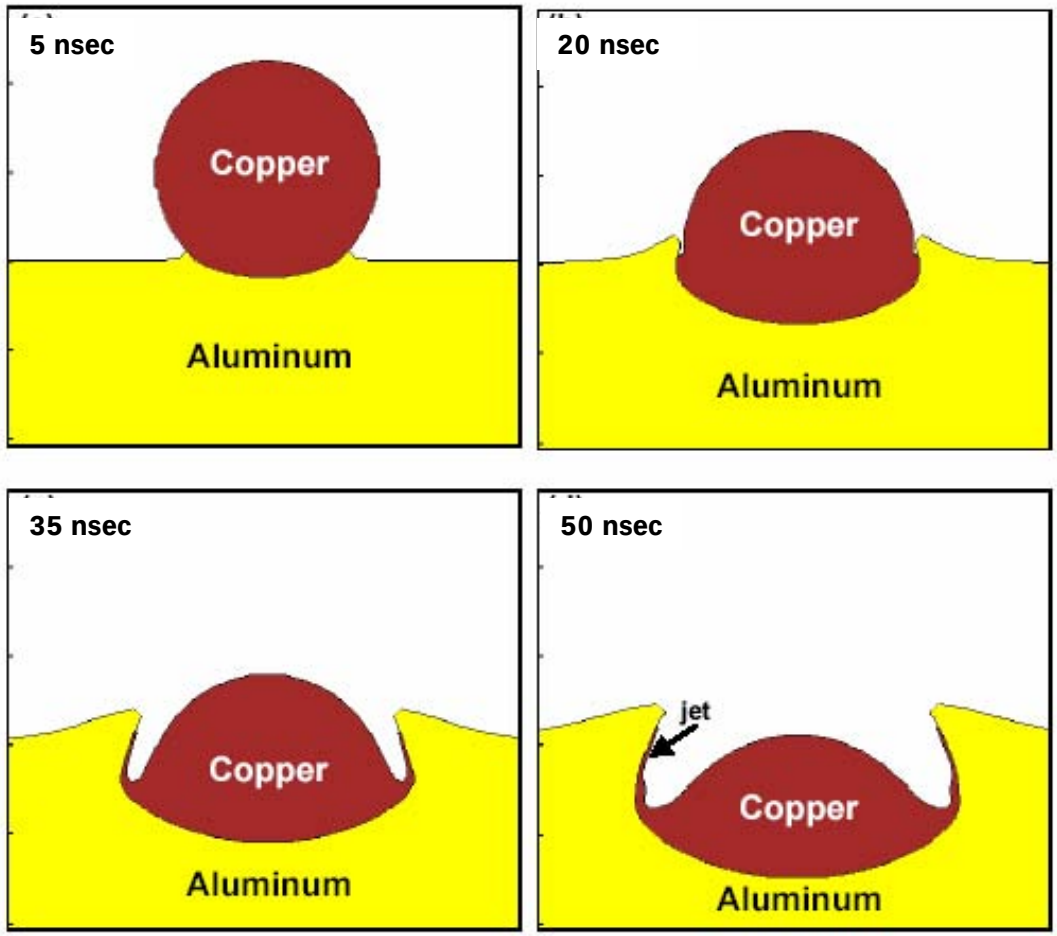
Army Research Laboratory
SPD System



SPD Advantages

- **Low temperature**
  - Solid State Process
  - Low residual stresses
  - Minimal grain growth
- **Little oxidation**
  - good electrical/thermal conductivity
  - electrical conductivity: 80% of OFHC Copper
- **High deposition rates and efficiencies**
  - rates - up to 20 kg/hr.
  - efficiencies generally 50 - 80%
- **Wide variety of coating materials and substrates**
  - Al, Zn, Sn, Cu, Ni, Ti, Ta, Co, Fe, Nb, Mo, W.

Model of Particle Impact*

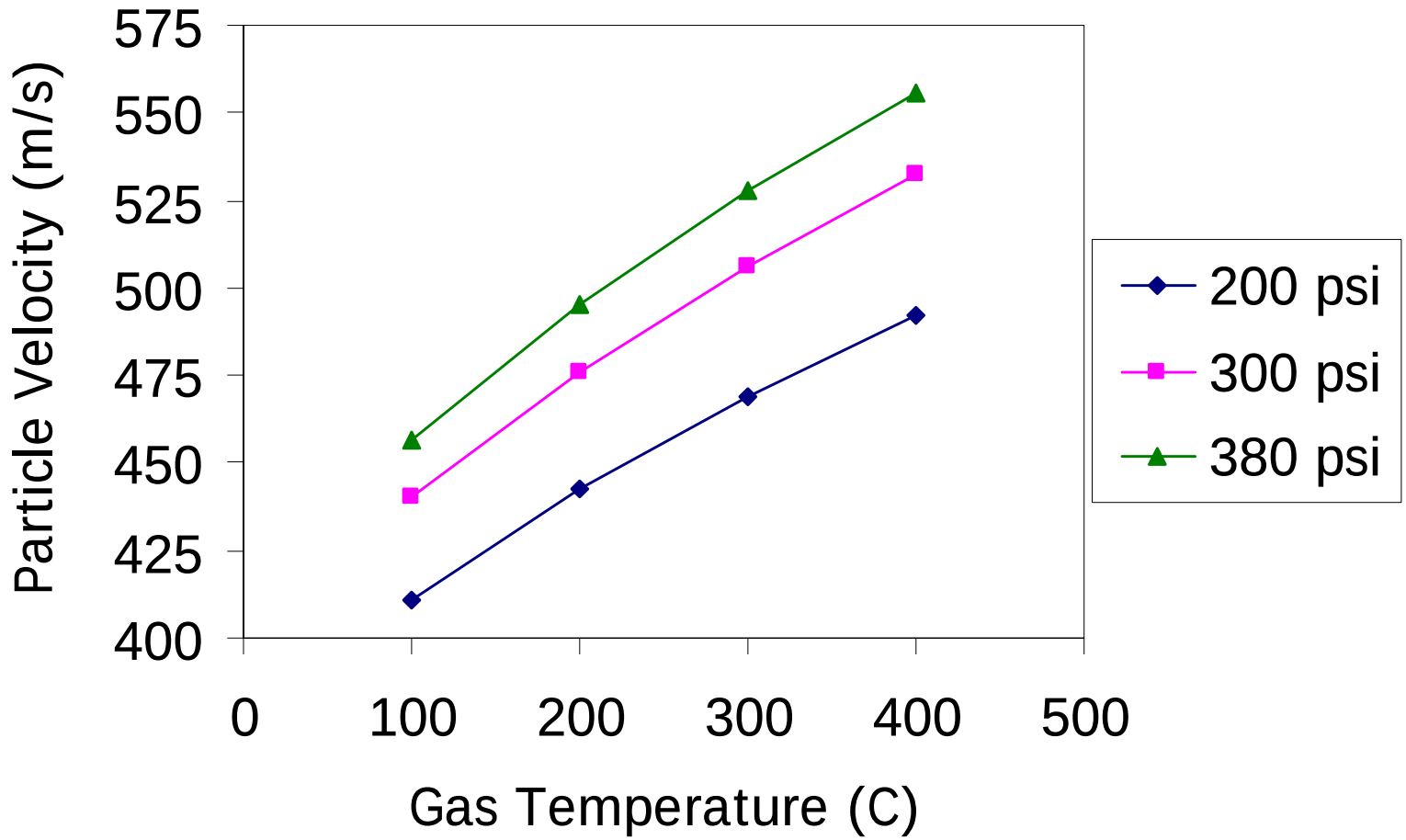


*M. Grujicic,et al, “Computational Analysis of the Interfacial Bonding Between Feed-Powder Particles and the Substrate in the Cold-Gas Dynamic-Spray Process”, Applied Surface Science, April 2003

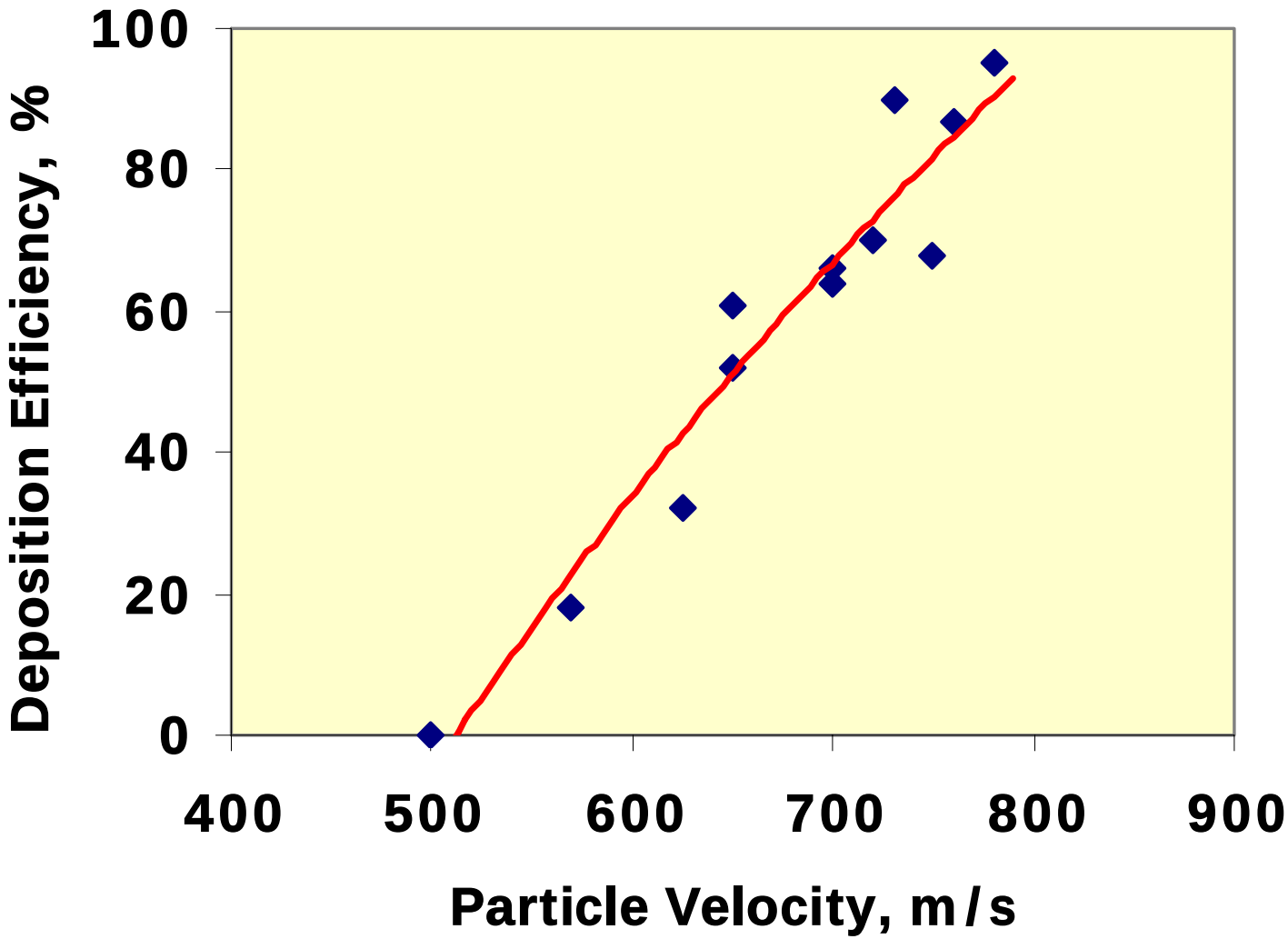
Process Parameters

- N_2 or He gas
- 200 – 500 psi gas pressure
- 200 – 500 degree C gas temperature
- 100 – 300 degree C particle temperature
- 1 – 50 micron particle diameter
- 300 – 1000 meter per second particle velocity
- 1 – 10 pounds per hour deposition rate

Effects of Gas Pressure and Temperature on Velocity

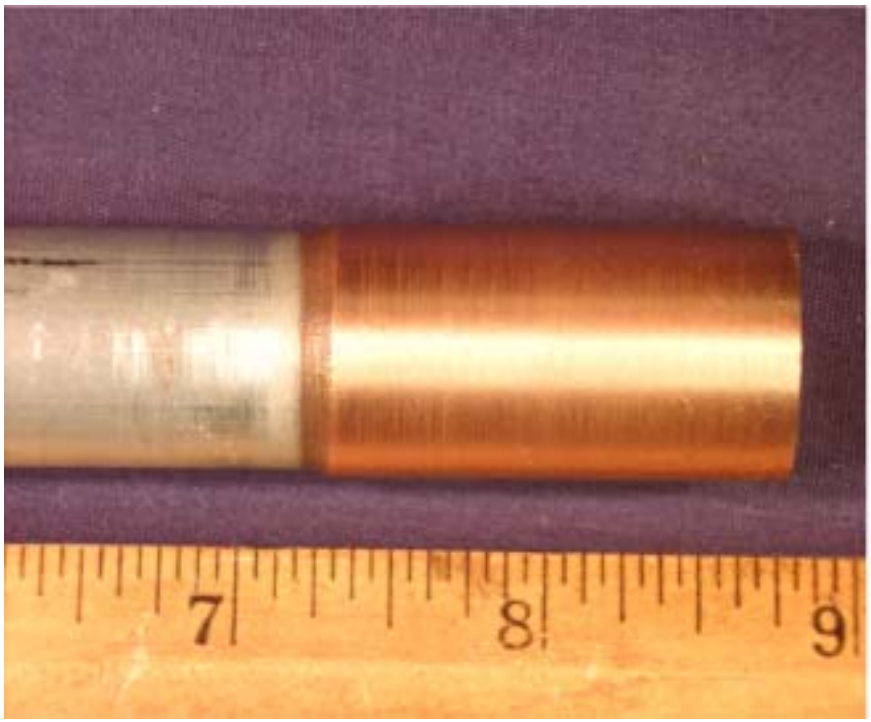


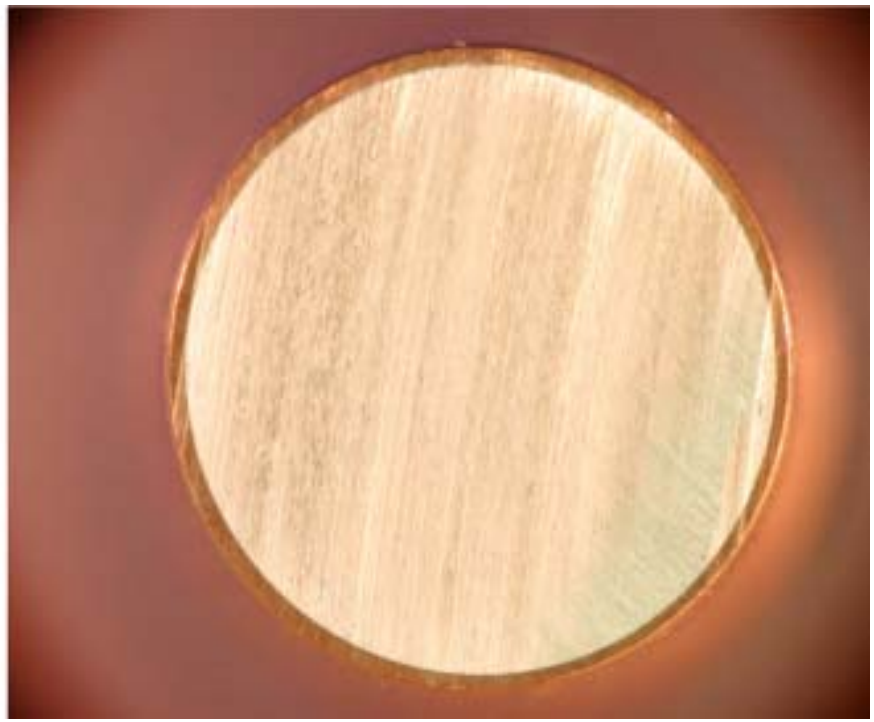
Effect of Velocity on Deposition



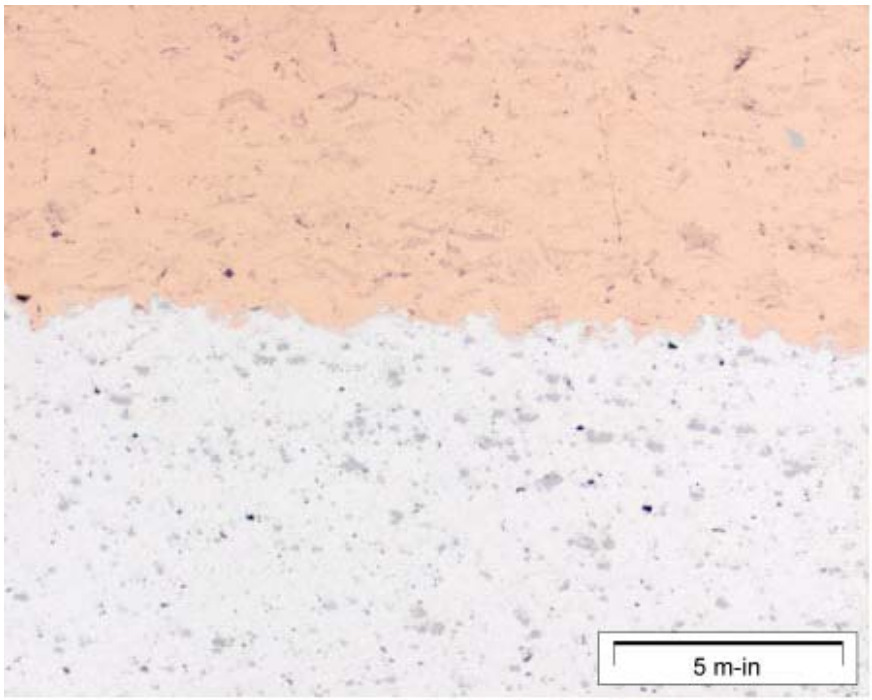
From Gilmore, et al, J. Thermal Spray Tech, Dec. 1999

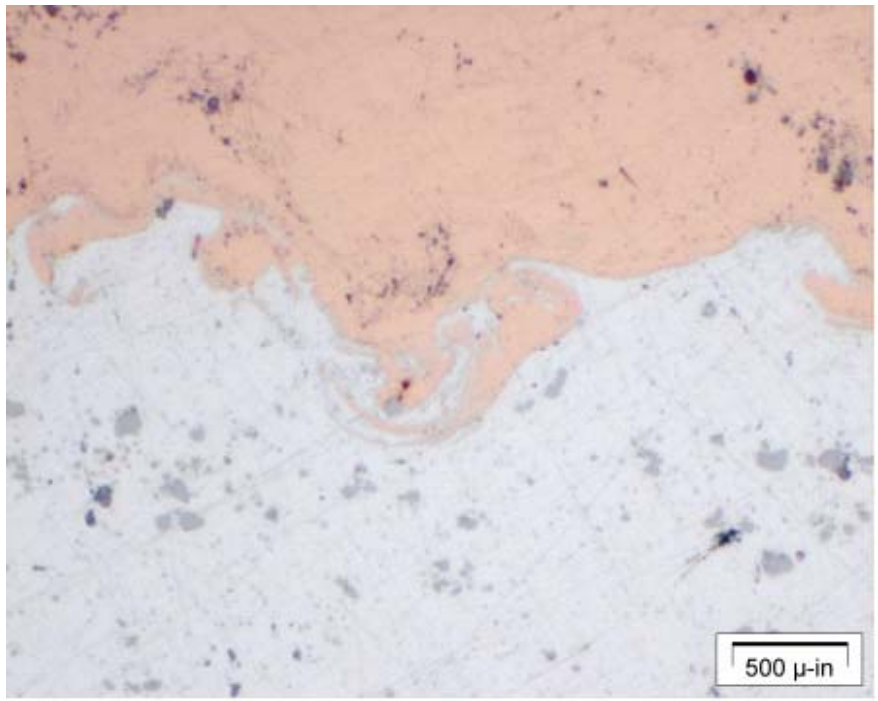
Copper Deposited On Aluminum Rod





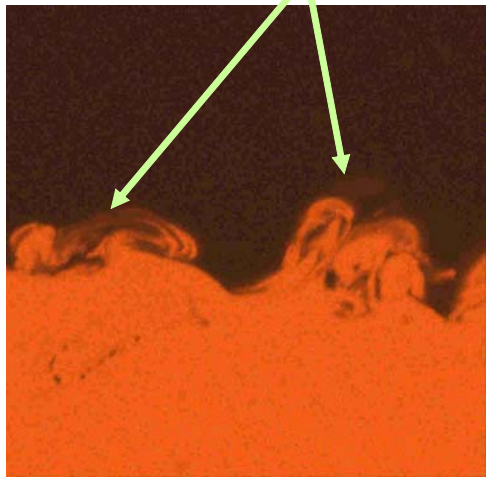
Magnified Interface
(Super Plastic Agglomerated Mixing)

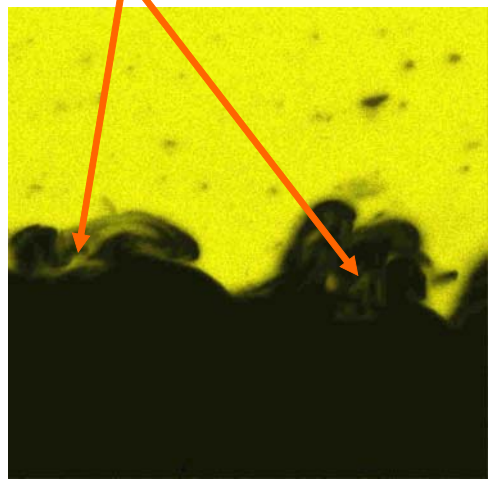




EDS X-ray Mapping of SPAM

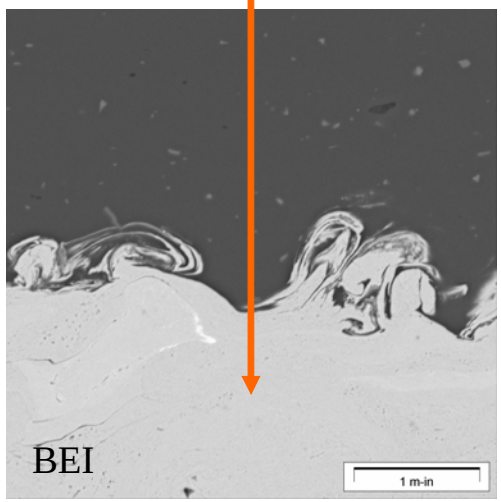
Forced mixing of copper and aluminum.

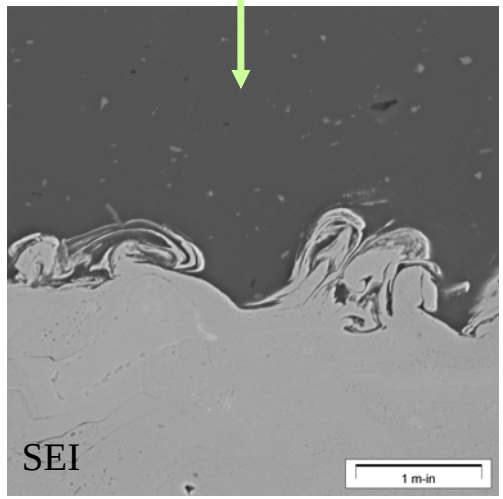




Copper SPD Coating

Aluminum Substrate





Shear Test Results
(Triple Lug Shear Test)

Trial	Pressure psi	Temperature degree C	Stand-off mm	Speed mm/sec	Feed rate gm/min	Shear strength psi
1	280	450	35	50	7	5347
2	280	350	15	50	28	6072
3	380	450	35	10	28	6683
4	380	350	15	10	7	10057

Failure Mode = Cohesive

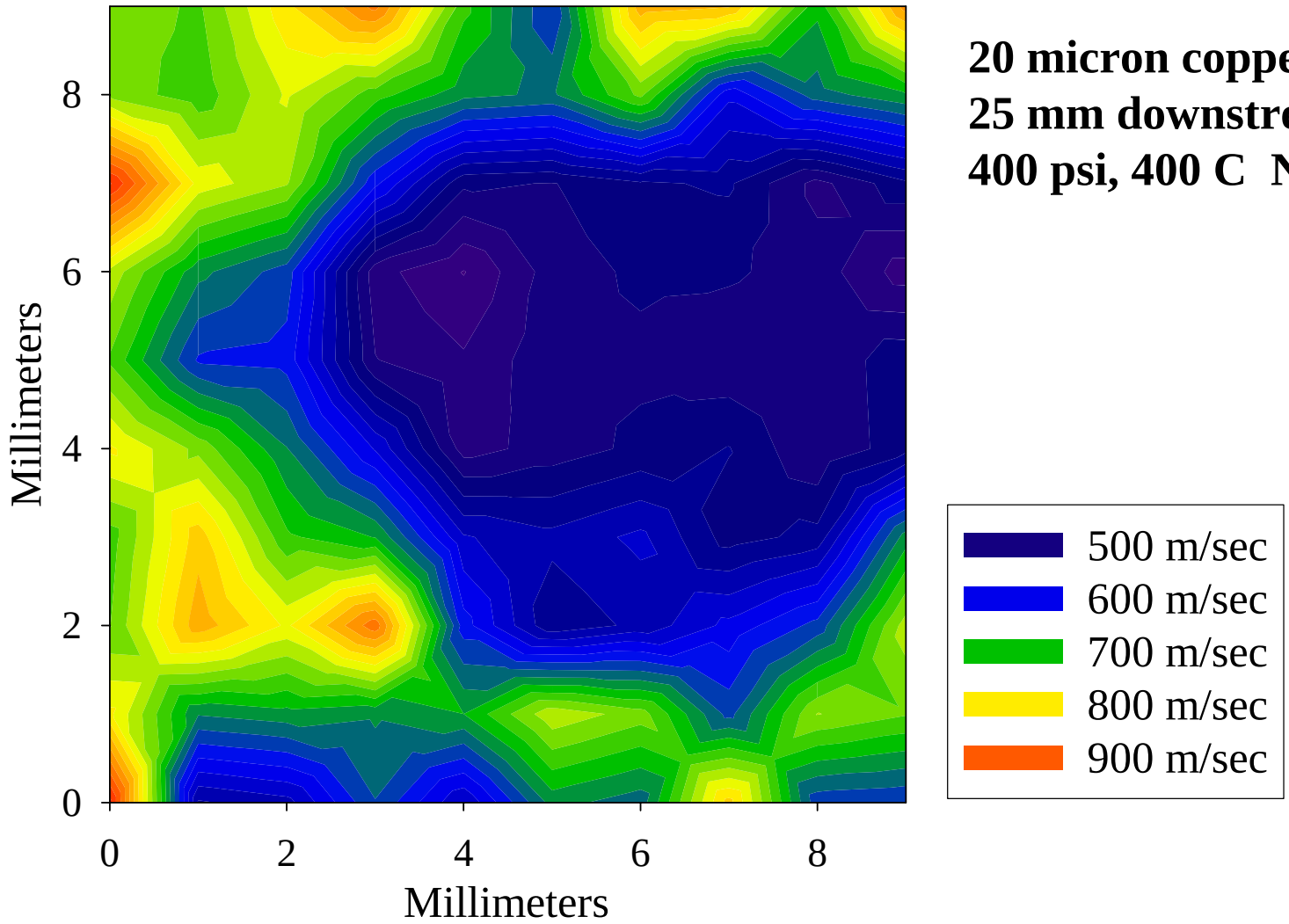
Adhesion Values of Coating (Bond Bars)

Coating	Thickness	Ultimate Tensile Strength
NiAl	0.015 in	5,000 psi
Tantalum	0.010 in	8,000 psi
Copper	0.010 in	6,800 psi

Failure Mode = Adhesive

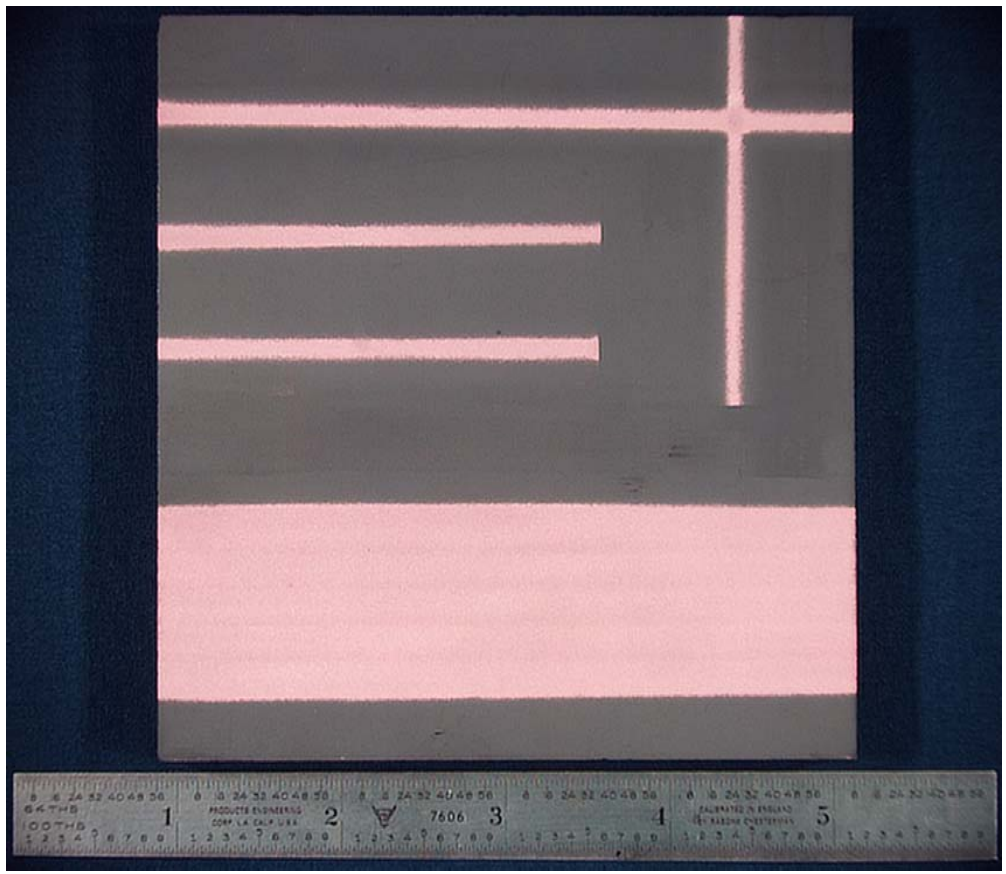
- All values of adhesion were of coatings deposited on aluminum

Particle Velocity Distribution



20 micron copper particles
25 mm downstream
400 psi, 400 C N_2 gas

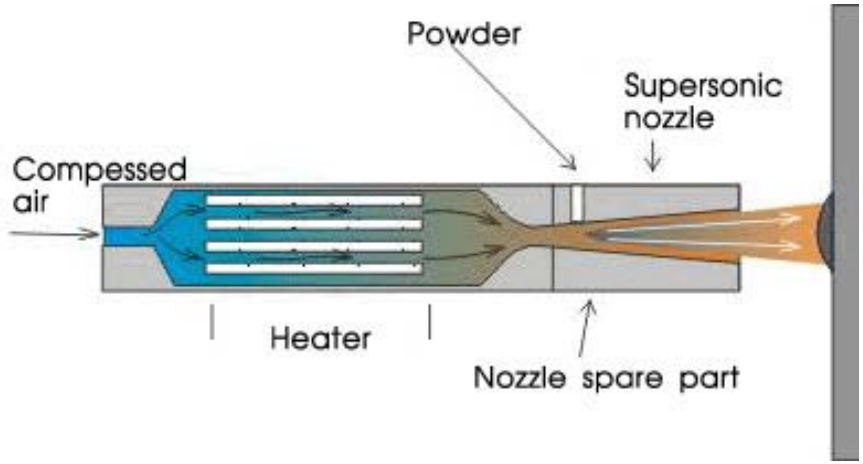
SPD Copper on Silicon Carbide



Copper on Silicon Carbide

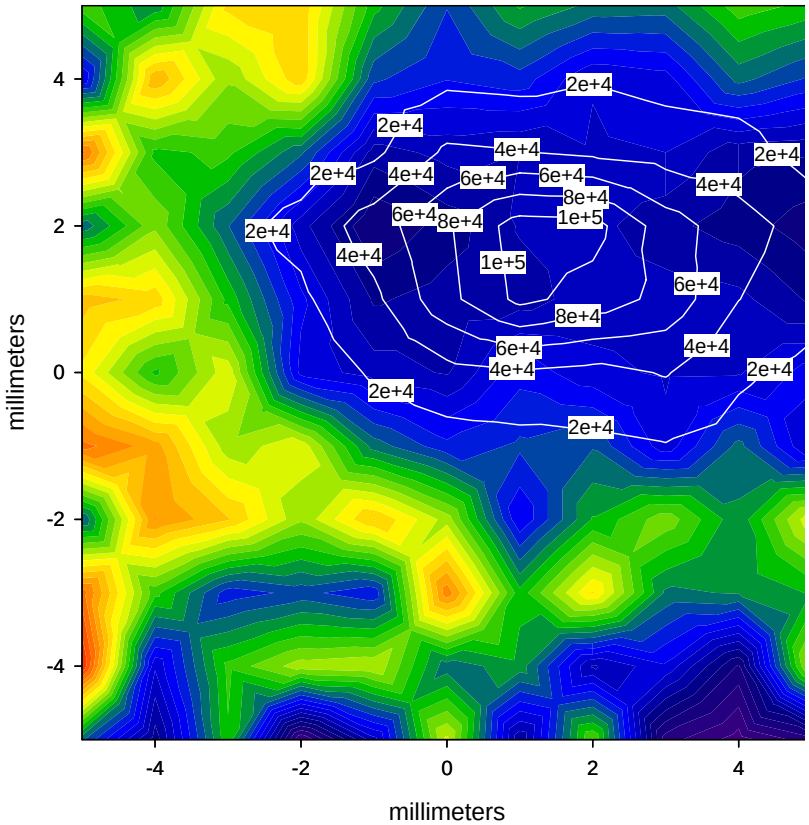
Bond Strength (Pull Test)	1500 lbs/in^2
Film Thickness	1-2 mils
Cu Resistivity (Theoretical)	1.7 x 10^{-6} ohm-cm
Cu Resistivity (Electronics)	2.0 x 10^{-6} ohm-cm
Cu Resistivity (Cold Spray)	4.5 x 10^{-6} ohm-cm

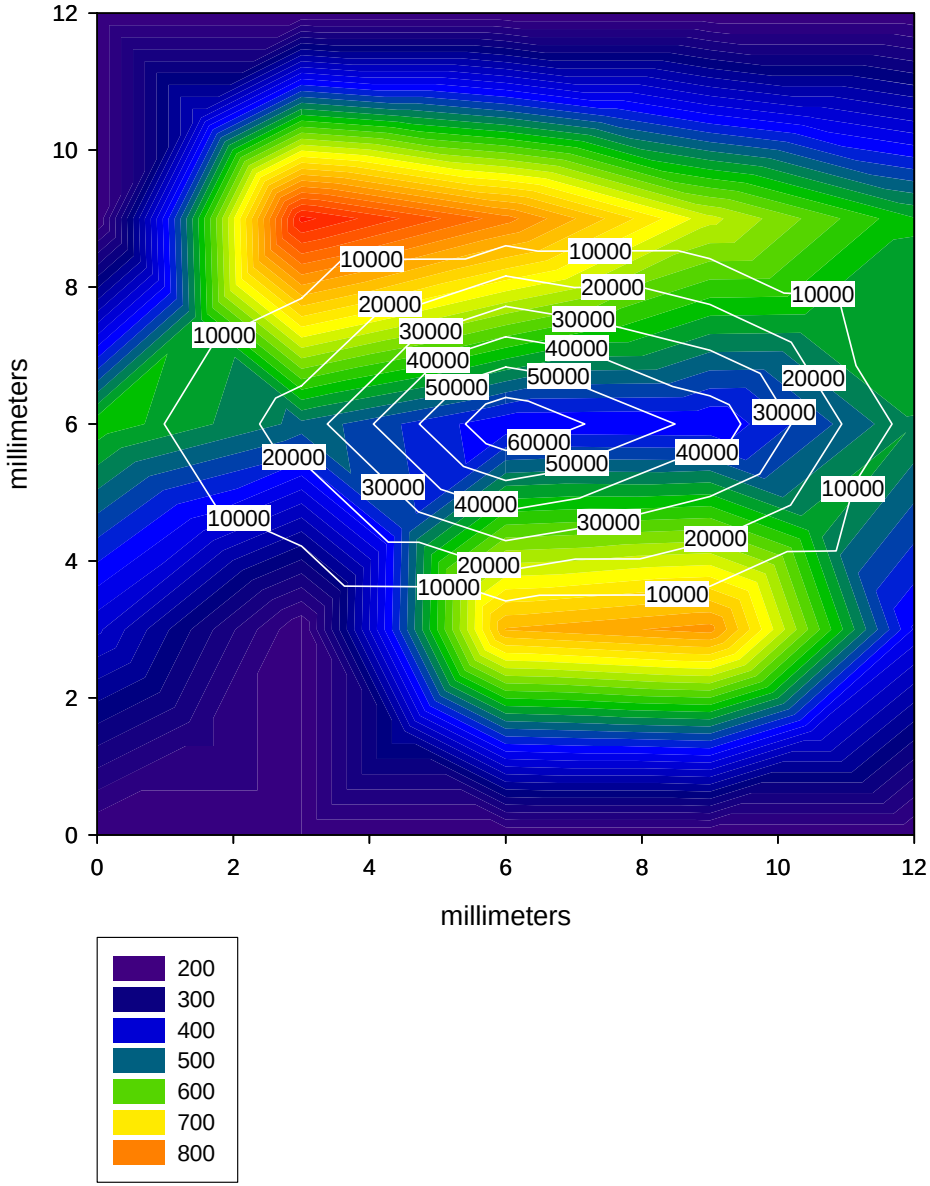
Dymet Portable Cold Spray



- Downstream Powder Feed
- Portability
- Slightly Lower Particle Velocity
- Special Powder Formulation

SPD and DYMET
Velocity and Particle Flux Profiles



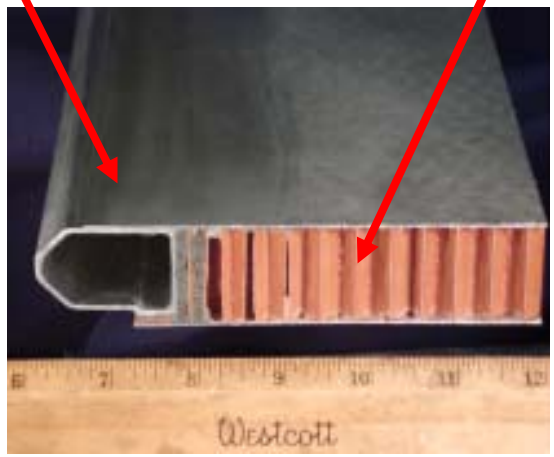


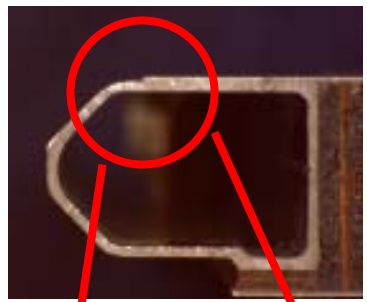
EMI Coating for HUMV Shelter (SPD)

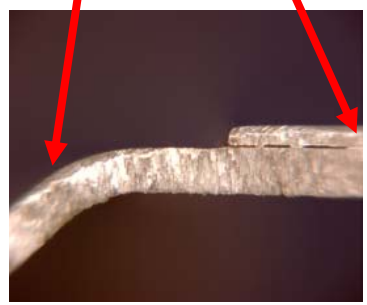
6061-T6 Al

Cross-section

Composite







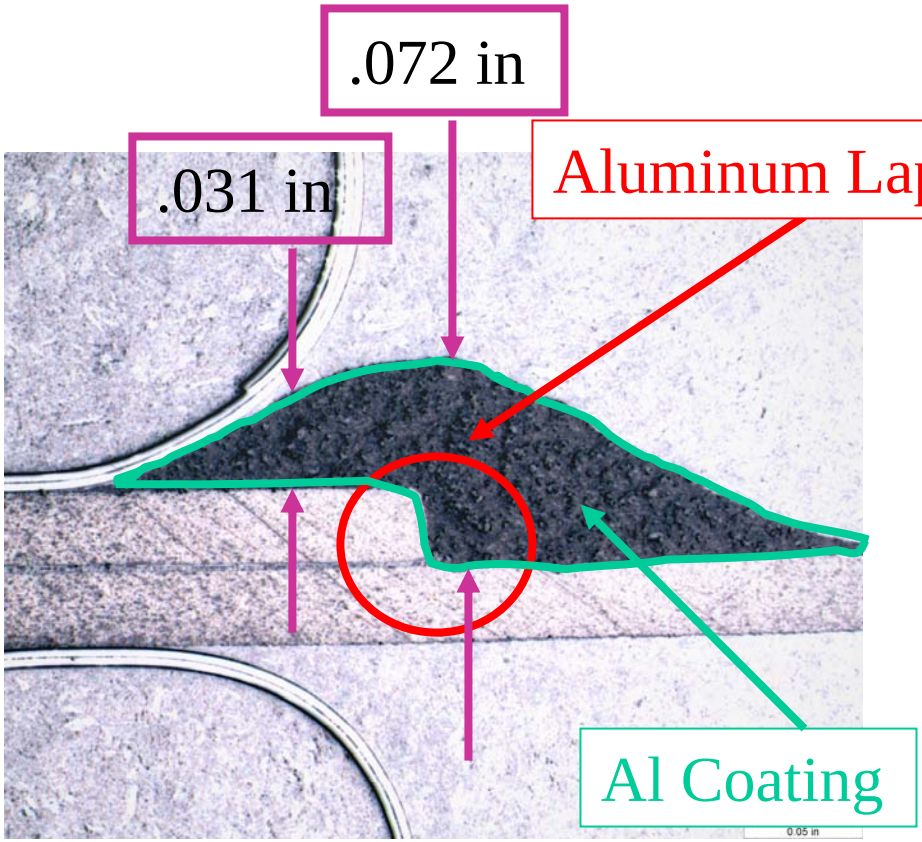
Lap joint

Enlarged

Supersonic Particle Deposition

Metallographic Cross-Sections of EMI Coatings

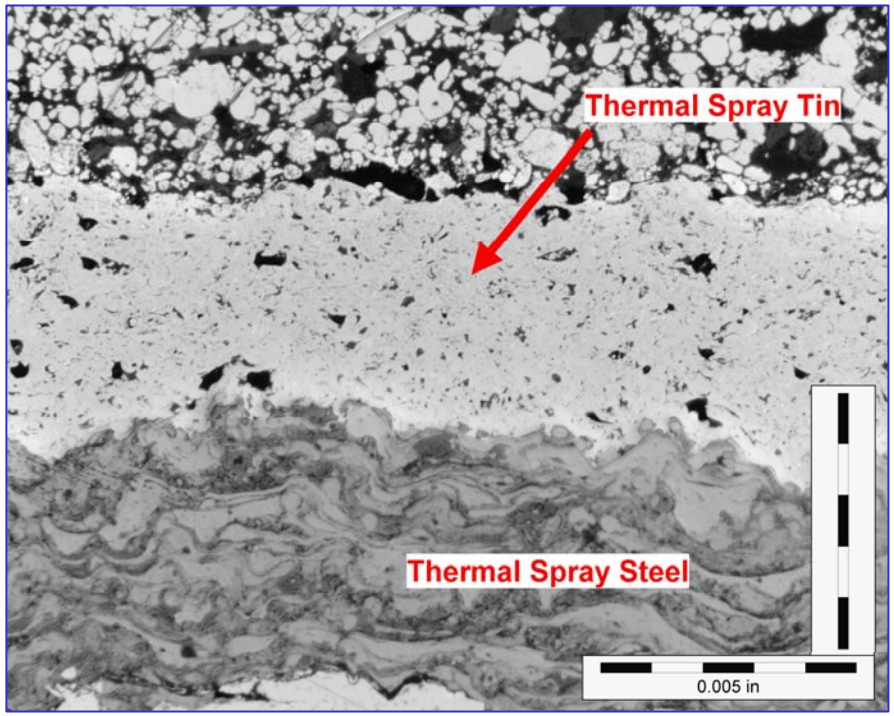
Supersonic Particle Deposition

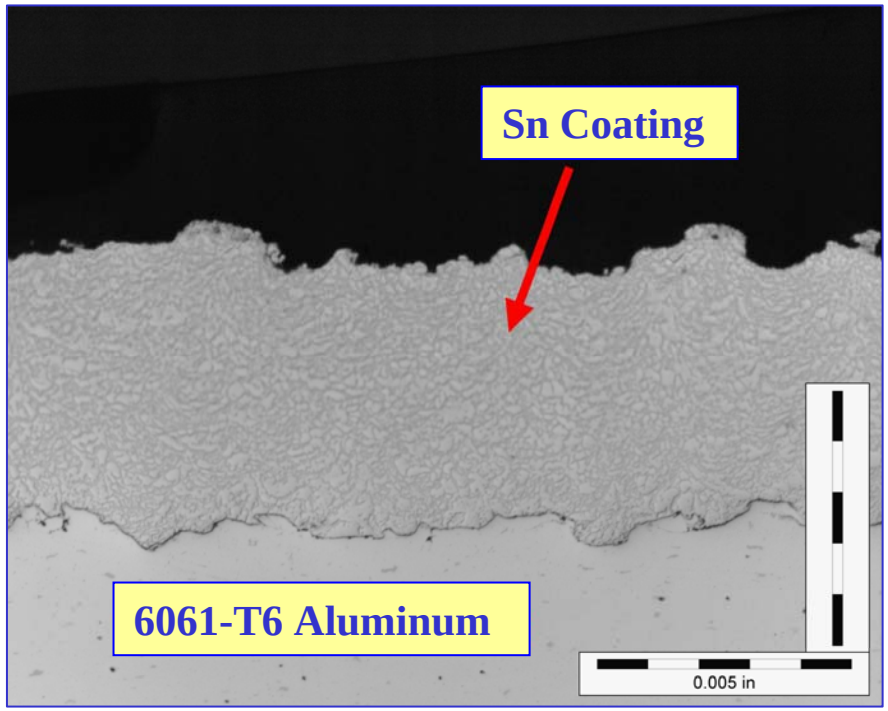


- .032” step height

Hand-held portable SPD System

Flame Spray vs. Supersonic Particle Deposition





Flame Spray Sn and Steel Coating

SPD Sprayed Sn Coating

~12.2% Porosity

~.18% Porosity

Conclusions

- Supersonic particle deposition can yield an exceptionally strong bond
- The bond can be characterized as “Super Plastic Agglomerate Mixing”
- High velocity impact yields plastic deformation and viscous mixing of the particle/substrate interface
- The resulting bond exhibits shear resistance greater than the shear strength of the copper coating.